



**Ontario Geological Survey
Open File Report 6163**

**Gravity and Magnetic
Three-Dimensional (3D)
Modelling:
Discover Abitibi Initiative**

2005



ONTARIO GEOLOGICAL SURVEY

Open File Report 6163

Gravity and Magnetic Three-Dimensional (3D) Modelling: Discover Abitibi Initiative

by

L.E. Reed

2005

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Discover Abitibi

A project of innovation, cooperation and revitalization

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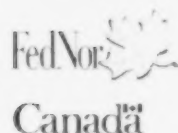
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Discover Abitibi Initiative

The Discover Abitibi Initiative is a regional, cluster economic development project based on geoscientific investigations of the western Abitibi greenstone belt. The initiative, centred on the Kirkland Lake and Timmins mining camps, will complete 19 projects developed and directed by the local stakeholders. FedNor, Northern Ontario Heritage Fund Corporation, municipalities and private sector investors have provided the funding for the initiative.

Initiative Découvrons l'Abitibi

L'initiative Découvrons l'Abitibi est un projet de développement économique régional dans une grappe d'industries, projet fondé sur des études géoscientifiques de la ceinture de roches vertes de l'Abitibi occidentale. Cette initiative, centrée sur les zones minières de Kirkland Lake et de Timmins, mènera à bien 19 projets élaborés et dirigés par des intervenants locaux. FedNor, la Société de gestion du Fonds du patrimoine du Nord de l'Ontario, municipalités et des investisseurs du secteur privé ont fourni les fonds de cette initiative.



KIRKLAND LAKE





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ASSOCIATED PUBLICATION

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Magnetic and Gravity 3D Modelling Products: Discover Abitibi Initiative

by L.E. Reed

This digital release was produced as part of the Discover Abitibi Initiative and consists of all the digital products of three-dimensional (3D) inversions discussed in Open File Report (OFR) 6163. The contents of this release consist of images and data for 10 study areas from west of Timmins to east of Kirkland Lake. All areas (except one) have been reported on through publications of the Discover Abitibi Initiative. Images are available as tagged image file format (.tif) and as bitmap (.bmp) files (accessible through various Windows-based viewing systems), which show the geology and many views of the 3D inversion of the magnetic and gravity data for each area. Binary (.bin) files are included for viewing using a three-dimensional viewer. Software (WinDisp 3DViewer version 3.00) for viewing the products of the 3D inversions and instructions for its use (in portable document format) are included with this release, with the permission of Scientific Computing and Applications, Adelaide, Australia, <http://www.scicomap.com>. Digital files (e.g., .sus and .den), which are the products of the University of British Columbia Geophysical Inversion Facility (UBC-GIF) magnetic and gravity inversion programs, are presented for use in other imaging systems or software. A detailed description of the contents of the disk is found in a readme file. The data in this release strongly augment OFR 6163, a digital version of which is provided in portable document format. All data sets are presented in Universal Transverse Mercator (UTM) Zone 17 using North American Datum (NAD83). The data and user documentation are available on 1 DVD.

This MRD is available separately from this report.

Abstract

Three-dimensional (3D) inversions of magnetic and gravity data were carried out on 10 areas in the Abitibi greenstone belt. The study areas extend from the Kamiskotia area west of Timmins, to Gauthier Township, east of Kirkland Lake. This study was a subproject of the Greenstone Architecture Project of the Discover Abitibi Initiative. The Discover Abitibi Initiative is funded by the private sector, the federal and provincial governments (respectively, Industry Canada through FedNor and the Ontario Ministry of Northern Development and Mines through the Northern Ontario Heritage Fund). The program is designed to stimulate mineral exploration in the Ontario portion of the Abitibi greenstone belt.

The 3D inversions were carried out using the University of British Columbia Geophysical Inversion Facility (UBC-GIF) inversion codes, and were run as uncontrolled inversions. The starting points for these inversions were magnetic maps from various airborne surveys and ground and airborne gravity surveys from the OGS gravity database and recent airborne surveying done under the Discover Abitibi Initiative. Images of these primary maps are presented. The products of the 3D inversions present density or magnetic susceptibility contrasts as isosurfaces in defined three-dimensional blocks that correspond with a software-generated model of the 3D source of the surface response.

Three-dimensional inversion magnetic and gravity images are imaged using a viewer and presented as viewable files within the viewer. Selected images are presented in this report as freeze-frame images (bitmaps) developed from various viewing aspects, so that the viewer can see the product without loading the viewing software. Viewing software (WinDisp 3DViewer version 3.00) is included as part of Miscellaneous Release—Data 162.

The content (the amount of point data) used to construct the primary images determines the resolution achieved in the inversion. The magnetic data have the highest resolution (survey lines spaced 50 to 150 m apart), and show dips, plunges and extensions to depth (a few hundred metres to several kilometres). The gravity inversions are less detailed as the primary data represents data points spaced an average of 1 km apart. These inversions show broad features commonly with substantial depth extent (several kilometres), which may complement or, in places, contrast with the magnetic inversions. A byproduct of this subproject has been the development of magnetic, gravity and geology maps which have been brought together in various viewing relationships. These provide the ability to refine the surface geology maps and distinguish among rock units not easily separated in the existing mapping. Geological interpretation, structure and stratigraphy in the third dimension are suggested by these results.



**Gravity and Magnetic Three-Dimensional (3D) Modelling:
Discover Abitibi Initiative**

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Open File Report 6163
2005**

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Introduction

The Discover Abitibi Initiative is funded by the private sector, the federal and provincial governments (respectively Industry Canada through FedNor and the Ontario Ministry of Northern Development and Mines through the Northern Ontario Heritage Fund). The program is designed to stimulate mineral exploration in the Ontario portion of the Abitibi greenstone belt and includes geophysical surveys of various types and geological projects (www.discoverabiti.com), such as the Greenstone Architecture Project, which is an "integrated geological study of the Timmins-Kirkland Lake area".

The Timmins-Kirkland Lake area of the Abitibi greenstone belt holds considerable promise for the development of views into the third dimension using 3D imaging. The geological view can be enhanced through integration of the surface geology with the three-dimensional view of stratigraphy and lithology derived from the geophysics. Thus, magnetic and gravity data have made it possible to carry out significant 3D inversions, and integrate these with the stratigraphic and lithological studies that are a central part of the Greenstone Architecture Project report (Ayer et al. 2005).

AREAS STUDIED

Three-dimensional inversions of magnetic and gravity data have been carried out on all of the project study areas of the Greenstone Architecture Project (Figures 1a and 1b; Ayer et al. 2005) for which the

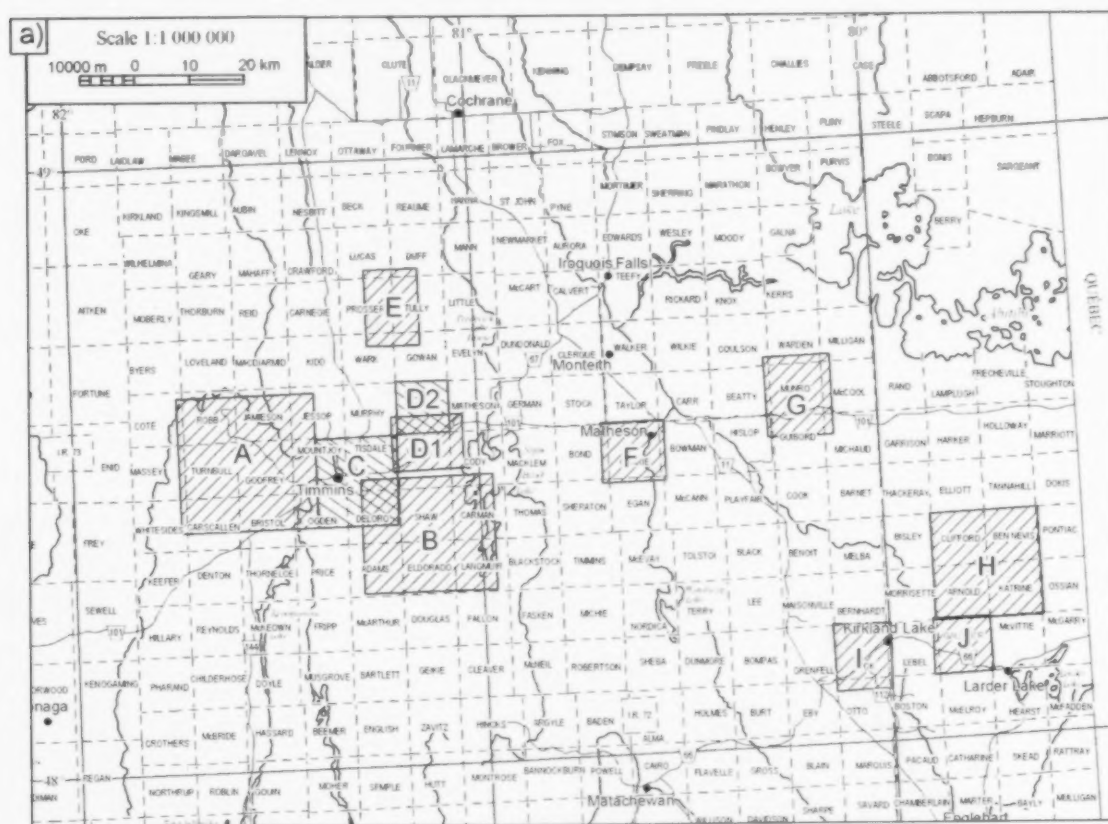
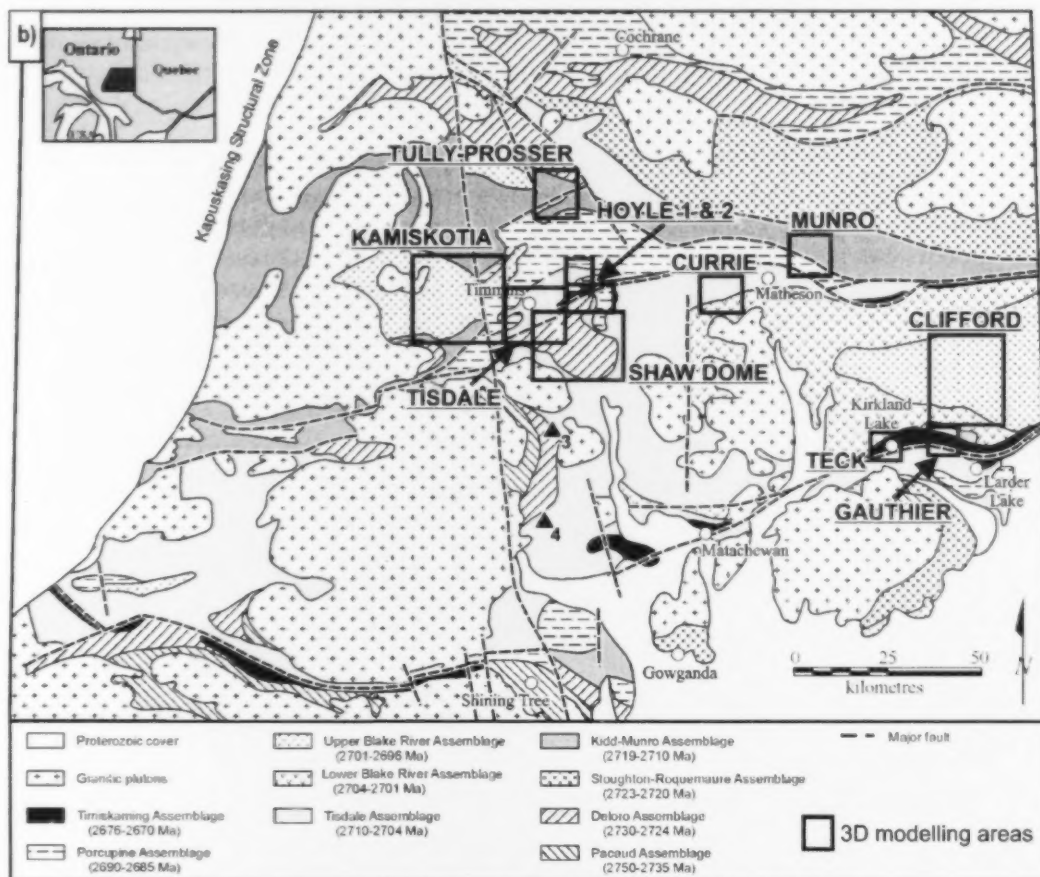


Figure 1. a) Locations of the study areas, showing the townships named in this report: A) Kamiskotia; B) Shaw Dome; C) Tisdale-Deloro; D) Hoyle-Whitney; D1) Hoyle 1; D2) Hoyle 2; E) Tully-Prosser; F) Currie; G) Munro; H) Clifford-Ben Nevis-Arnold-Katrine; I) Teck; and J) Gauthier.

following Open File Reports (OFR) or other reports have been published:

1. Kamiskotia area (OFR 6155: Hathway, Hudak and Hamilton 2005)
 - a) western Godfrey Township, enclosing Genex deposit area (OFR 6156: Hocker, Thurston and Gibson 2005)
2. Shaw Dome area (Houlé and Guilmette 2004)
 - a) detail (2 areas)
3. Tisdale-Deloro townships (OFR 6158: Bateman et al. 2005)
4. Hoyle-Whitney townships (2 overlapping areas) (OFR 6158: Bateman et al. 2005)
 - a) Hoyle 1; b) Hoyle 2
5. Tully-Prosser townships (an early assignment, eventually not a geologically studied area)
6. Currie Township (OFR 6157: Péloquin, Houlé and Gibson 2005)
7. Munro Township (OFR 6157: Péloquin, Houlé and Gibson 2005)
8. Clifford-Ben Nevis-Arnold-Katrine townships (OFR 6160: MacDonald, Piercey and Hamilton 2005; and OFR 6161: Péloquin and Piercey 2005)
9. Teck Township (OFR 6159: Ispolatov et al. 2005)
10. Gauthier Township (OFR 6159: Ispolatov et al. 2005)

All data and map elements are provided as Universal Transverse Mercator (UTM) in Zone 17 using North American Datum 1983 (NAD83). The bounding UTM co-ordinates of the study areas are listed in Appendix 1.



THREE-DIMENSIONAL INVERSION OF POTENTIAL FIELDS

The responses in geophysical data gathered on the ground or in the air derive from physical parameters or contrasts in physical parameters in rocks and materials below the ground surface. Contained minerals contribute to these responses. It is a goal in the interpretation of geophysics to identify the three-dimensional distribution of the sources of the geophysical responses. One way to develop this information is to interpret the passive measurements of potential fields (magnetic and gravity). These observe variations in fields caused by variations in magnetic susceptibility and density (specific gravity) in the rocks, minerals and materials in the vicinity of the observation points.

At the present time, three-dimensional (3D) inversion of potential fields is being used to develop images of source bodies (Li and Oldenburg 1996, 1998a; MAG3D 1998; GRAV3D 2001). Three-dimensional potential field imaging has been used to interpret regional- and mineral deposit-scale environments (Boulanger and Chouteau 2001; Oldenburg, Li and Ellis 1997). While 3D images presented as magnetic susceptibility or density contrasts need to be treated with some care and caution, as a number of solutions are possible with potential field data, they represent a significant advance over previous simple model interpretation methods.

The Timmins-Kirkland Lake area of the Abitibi greenstone belt holds considerable promise for the development of views into the third dimension using 3D imaging. The geological view is enhanced through integration of the surface geology with the three-dimensional view of stratigraphy and lithology derived from the geophysics. Ground-based gravity, airborne gravity and airborne magnetic surveys are available across the study area. The existing geophysical database varies in detail and quality, but new data with higher resolution and definition have been collected as part of the Discover Abitibi Initiative (OGS 2003b, 2003c, 2003d, 2004a, 2004b, 2004d). These old and new databases for magnetic and gravity data have made it possible to carry out significant 3D inversions, and integrate these with the stratigraphic and lithological studies that are a central part of the Greenstone Architecture Project report (Ayer et al. 2005).

POTENTIAL FIELDS AS FLAT MAPS AND ENHANCED AMPLITUDES MERGED WITH GEOLOGY

Gravity and magnetic maps generally appear as flat maps, representing the appropriate parameters. These parameters may be at surface or above surface at some elevation determined by the airborne survey that collected the data. All of the magnetic data and some of the gravity data presented here were collected from the air. Most of the gravity data were collected on the ground. There are various sources for these data, as identified in this report. Acquisition spatial and resolution parameters vary and do have an impact on the final product. Attempts have been made to minimize variations and unify the 3D product for consistent behaviour. In some cases, with the new Discover Abitibi Initiative high-resolution magnetic data, smoothing has resulted in a loss of detail (e.g., degrading 12.5 m cells to 200 m cells proved necessary in places, e.g., Teck Township and Gauthier Township study areas). The development of 3D inversions that retained the original detail would necessitate selection of smaller areas for study.

Some processing has been done to optimize the gravity and magnetic data. The magnetic data are delivered with the IGRF (International Geomagnetic Reference Field) removed, and the grid has been levelled to the Ontario master magnetic grid. The total Bouguer gravity response has been filtered to remove a broad regional field, leaving local anomalies arising from relatively near-surface sources. The filter used was a 10 km bandpass in all but one case. This filter (Geosoft® source) processes the gridded Bouguer response to remove all wavelengths longer than 10 km (and less than 100 m). The resultant

response shows sources having widths of up to 5 km and having depths and depth extents of 2.5 km or larger. It will be noted that these maps correlate reasonably with generalized surface geology. It has been proven beneficial to use flat-map gridded data with the regional field removed (for both magnetic and gravity data) for the 3D inversions (Gupta and Ramani 1980; Li and Oldenberg 1998b). The inversions then focus on the near-surface events.

A mode of presentation (WinDisp from Scientific Computing and Applications) uses the amplitude of the responses as an elevation surface. To this may be added the colour grids of the potential fields or the geology derived from a tagged image file format (TIFF) or bitmap image. This amplitude enhancement significantly improves the way of viewing magnetic and gravity data and geology together. Geology may be superimposed on amplitude-enhanced magnetic or gravity data, and magnetic and gravity data may be placed on themselves or interchanged with magnetic on gravity or gravity on magnetic. This is not 3 dimensions as in the ordinary sense of spatial XYZ, but response amplitude used as a third dimension on an XY flat map. Examples are presented for all of these study areas. Some images incorporate line drawings (from DXF files) of topography and geology at the surface to provide better location information for the 3D images.

Both the enhanced-amplitude and flat presentations of the gravity and magnetic data improve the interpretation of the surface geology map as the potential field responses reflect the near-surface lithologies and "see through" the extensive cover in the region. The 3D products go beyond this and permit a view of the potential field sources in the spatial third dimension.

THREE-DIMENSIONAL MAGNETIC AND GRAVITY DATA, REGIONAL AND RESIDUAL ELEMENTS, POSITIVE AND NEGATIVE VALUES

It has been noted that total potential field data contain regional and residual elements across a spectrum in the data (Li and Oldenburg 1998a, 1998b). The need to resolve local elements for inversion to local features requires the removal of the regional elements.

The magnetic map has had the IGRF removed, thus removing the large regional magnetic field component. Further, the magnetic anomalies in the Abitibi area map almost invariably are positive from a regional background. There are no significantly reversed magnetic anomalies in the areas studied. The 3D inverted images of the magnetic data, then, are from local sources and are positive.

This is not the case with the gravity data, where the Bouguer maps drawn from the gravity database and the airborne survey contain all the gravity response from shallow to deep. It is necessary then to develop a residual map for inversion. This was accomplished by filtering with a 10 km bandpass filter. This filtering process, using a grid filter in Geosoft® (BPAS format in SUSHI), includes wavelengths from 100 m to 10 km through a Fourier transform.

The 10 km bandpass filter run on the Bouguer gravity data produced a map with approximately equal parts positive and negative Bouguer residual values overall, although locally, there may be an emphasis on one or the other. Values of the gravity response in milligals, represent departures from a median value. Anomalies may be positive, representing rocks with densities higher than a local background; or negative representing rocks with densities lower than the local background. Negative or low gravity values have been developed into 3D images by processing the flat-map grid multiplied by -1. The same result may be achieved by multiplying the product of the inversion by -1, but this has proven computationally difficult because of the size of the inversion product. Images will be found separately and combined showing both the 3D positive and negative interpreted bodies. Recent additions to the WinDisp software permits converting the inversion model directly to negative components, but these were not available for this study.

ACKNOWLEDGEMENTS

The author is indebted to the project geologists Michel Houlé and Lindsey Hall (Shaw Dome), Shirley Péloquin (Currie), Vlad Ispolatov (Teck, Gauthier), Roger Bateman (Hoyle, Tisdale), and Ben Hathway (Kamiskotia) for discussions about their study areas and to the Greenstone Architecture Project coordinator, John Ayer, for general discussions and review of this report.

Three-Dimensional Process

Three-dimensional inversion of magnetic and gravity data processes flat-map images to develop three-dimensional images of bodies under the flat maps. The 3D bodies could be (or are most likely to be) the sources of the flat map responses, although potential field theory denies the possibility of unique solutions. Flat-map images are the gridded images of line or interval amplitude data collected either from the air or on the ground. The amplitudes represented in these images are numerically sampled in a regular fashion, then processed in software designed to develop images of the three-dimensional source bodies. The software used in this subproject was developed at the University of British Columbia Geophysical Inversion Facility (UBC-GIF). Separate software programs for 3D inversion of magnetic and gravity data were employed (Li and Oldenburg 1996, 1998a; MAG3D 1998; GRAV3D 2001).

Preparation of the files for inversion employed the use of Geosoft® Inc. OASIS montaj™ software to image and extract the numerical data amplitudes derived from gridded airborne and ground-based data with selections of cells with a size useful to the particular inversion. The required input files for the inversion were then developed in a Microsoft® Excel spreadsheet and exported to text files. (The observation files [*.obs*] in the directories are the products of this process.) The 3D inversions were then carried out on the magnetic and gravity data (as defined by the *.obs* files). Image display tools employed WinDisp processing of the 3D model, then viewed using the WinDisp 3DViewer. The depths of the inversions were set in the mesh file (*.msh* or *.mesh*) to provide a reasonable look in depth without developing artifacts or overly extended models at depth.

The airborne magnetic inversion products are much better resolved than the gravity data because of their very different primary data definition. The magnetic data are highly defined, while the gravity data are relatively poorly defined. The cell sampling used for the inversion moderately to significantly undersamples and degrades the magnetic data, whereas the same size sampling significantly oversamples the gravity data.

The product of the inversion is developed as a 3D mesh (a set of cubes), which is set by the individual doing the processing. The mesh consists of cells of defined size, possibly varying in size across the 3D space, that have values either of magnetic susceptibility contrast or density contrasts that are developed by the inversion. This subproject has employed a common X and Y dimension (usually 200 m) and a depth dimension (Z) that may be half the dimension of the X and Y dimension, but here is mainly 125 m, or longer than half the surface interval. The output may be viewed using imaging tools (e.g., MeshTools3D) developed at UBC-GIF (MeshTools3D 2004). MeshTools3D software permits viewing the 3D mesh with colours assigned to amplitudes. The inversion may be viewed in various aspects and transferred to flat images such as bitmaps (*.bmp*), JPEGs (Joint Photographic Experts Group or *.jpg*) or TIFFs (tagged image file format or *.tif*) images.

This subproject employed a processing and viewing set of programs called WinDisp (Scientific Computing and Applications, www.scicomap.com). An imaging component of WinDisp, 3DViewer, which is significantly different in its presentation than the UBC-GIF MeshTools3D, has been used to

develop three-dimensional views of magnetic and gravity isosurfaces, each surface or shell representing constant susceptibility or density contrasts. The shells are presented as smooth surfaces in contrast to the mesh cubes viewed in MeshTools3D. The 3D image may be turned or rotated to view various aspects of the 3D inversion product. With this, sections or slices, with other aspects of interpretation, have been drawn to provide hard-copy or freeze-frame images of the inversions (presented here as bitmaps). WinDisp has permitted the introduction of the primary, surface flat-map grid image and line information (as from DXF sources) such as topography and geology. Flat images may be produced from computer screen views as standard TIFF, JPEG or bitmap format files for display, interpretation and image file transfer. Other, more sophisticated imaging programs, such as GoCAD or GeoExpress2000, may be used to develop 3D interpolations or interpretations of geology merged with the 3D inversions of the magnetic and gravity data. This last level of detail was not envisioned for this subproject. The 3D inversion products are available for later or separate use in this manner (as *.sus* for the magnetic model, and *.den* for the gravity model).

A foreseen difficulty has been the limited availability of software to view the 3D product. This, in part, has been resolved by making static images of the inversion product standard file formats. The 3D images for use in the viewer are binary (*.bin*) files. It may be possible to use WinDisp 3DViewer to create rotating images of the inversion (a movie) for use in Microsoft® PowerPoint presentations, but this may have limited value. Most important has been the bringing together of the 3D geophysical inversions with surface and third-dimension geological interpretations. New thinking has been brought to bear on this problem, as some of the necessary cross fertilization between geology and geophysics has been achieved. Controlled 3D inversion tests using interpretations of the third dimension of the geology have not been accomplished at this time, and remain as an opportunity to be realized. Hopefully, geologically and geophysically consistent 3D models of the Earth can be achieved in the future. Variances between surface geology and flat-map magnetic data are identified in some places; the magnetic data illustrate the need to revise the inferred geology map in places.

The digital data and images on Miscellaneous Release—Data (MRD) 162 (Reed 2005) augment, and are integrated with, this report. Throughout this report, references are made to images on MRD 162, with the paths for specific files provided for easier access. In addition, Appendix 2 provides references for Figures 2 to 30 (Charts A to D, back pocket) to the image file on MRD 162. Also, WinDisp 3DViewer, with instructions on its use, is provided with the images and data on MRD 162.

SOFTWARE USED

A number of different software packages have been used to convert and display the various 3D and related images.

University of British Columbia Geophysical Inversion Facility (UBC-GIF) Gravity and Magnetic 3D Inversion Codes: Two separate processes (GRAV3D for gravity and MAG3D for magnetic data) were used for converting surface plan data into three-dimensional images of likely source bodies (UBC-GIF, <http://www.eos.ubc.ca/research/ubcgif/> [accessed July 6, 2005]). The gravity inversion is an updated version by Y. Li, following an earlier format (Li and Oldenburg 1997).

Geosoft® OASIS montaj™ and SUSHI: used for various aspects of gridding primary data, merging various source data, filtering grids, creating XYZ files in preparation for 3D inversion. Grid conversions from NAD27 to NAD83 where necessary. Conversion and windowing of ESRI® ArcGIS shape (*.shp*) files (line topography and line geology) to DXF for use in WinDisp. (Geosoft Inc., <http://www.geosoft.com> [accessed July 6, 2005])

Microsoft® Excel 2000: used to manipulate files in preparation for submission to the 3D inversion program.

ESRI® ArcGIS 8.3: used to convert map images to format (.shp) accessible by OASIS montaj™ for “windowing” and conversion to DXF files used in image presentation. Convert map images to georeferenced TIFF images brought into WinDisp for display with magnetic, gravity and 3D images. (Environmental Systems Research Institute, Inc., <http://www.esri.ca> [accessed July 6, 2005])

WinDisp: 3D processing software to convert 3D inversion products into data format accessible for viewing. Prepares DXF map elements for viewing with 3D inversion products. Prepares OASIS montaj™ gridded data for display in 3DViewer as both flat and amplitude-enhanced images. (Scientific Computing and Applications, Adelaide, Australia, <http://www.scicomap.com> [accessed July 6, 2005])

WinDisp 3DViewer: presents 3D views, grids and line drawings output from WinDisp that can be merged and output as fixed bitmap images. This software is available from John Paine, Scientific Computing and Applications, Adelaide, Australia (www.scicomap.com); WinDisp 3DViewer version 3.00 and instructions are provided with the inversion products in MRD 162, with the permission of John Paine, Scientific Computing and Applications.

Computer System Requirements

The WinDisp 3DViewer works best in a Windows® NT or Windows® XP environment with memory of 1GB of RAM and operating speed of 1GHz (or more). The 3DViewer will function on computers with more limited capacity, but will be slower and may freeze during use.

DATA AND IMAGE PRESENTATION

The digital data are presented in consistently arranged folders on MRD 162:

<u>main folder</u>	<u>subfolder</u>	<u>sub-subfolder</u>
Study Area name	3Dgrav	binary (.bin)
		bitmap (.bmp)
		inversource (.den, .msh, .obs)
		TIFF (.tif, .tiff)
	3Dmag	binary (.bin)
		bitmap (.bmp)
		inversource (.sus, .msh, .obs)
		TIFF (.tif, .tiff)
	combined	binary (.bin)
		bitmap (.bmp)
	geology	various formats (e.g., .tif, .bmp, .tiff, .bmpw)

The digital file products on MRD 162 are set out in separate folders for magnetic and gravity data that should be self explanatory. Within these folders are binary (.bin) files for use with the WinDisp 3DViewer. The bitmap (.bmp) format files were developed in the viewer for viewing static images. The source files (in the inversource folder) were used for the inversion that give the mesh description (cell sizes), and the observed file that shows where the surface survey is sampled and the error employed. The model (.sus and .den) files, which are the direct products of the inversion, are in the inversource folder as well. There is a folder (“combined”) containing both binary and bitmap format files, where a few

combined magnetic and gravity shells are observed together. The "geology" folder contains georeferenced TIFF images and bitmap format files of the base geology (*from* digital versions of figures in Ayer and Trowell 1998, 2000; Ayer, Berger and Trowell 1999; and, for the Clifford Township study area, an image *from* Péloquin and Piercey 2005).

TIFF images (.tif) of both gravity and magnetic flat maps with line geology and separate topography overlays have been made for some of the areas (Kamiskotia, Shaw Dome) studied earlier in this subproject. Areas studied later are presented as plain magnetic and gravity images. The earlier work is presented both as ESRI® ArcView® georeferenced tiffs ("av" in the file name) and MapInfo georeferenced tiffs ("mi" in the file name) out of Geosoft® OASIS montaj™. Township outlines are located on these maps (although without names) so that the observer may be oriented to the location. This practice was dropped in later parts of the subproject as full colour images of the geology were brought into use (also presented as TIFF images and used to drape amplitude-enhanced magnetic and gravity images). In some areas, the practice of showing geology with township names in the drape was employed.

The colour figures in this report (Figures 2 to 30 on Charts A to D, back pocket) represent a sampling, with commentary, of a few images from each area. These are developed from the TIFF images. Appendix 2 provides references for the figures to the image on MRD 162.

At first, there may seem to be a lot of images. After some use, the number and formats of the images will become familiar. The place to start, after the figures, is with the flat-map TIFF images to get a sense of the magnetic and gravity field and the geology from the separate geology directory; then the bitmap images, which show various views from different viewing directions, and slices through the models; then look at the binary image files using WinDisp 3DViewer where the images can be rotated, translated, made transparent, sliced, and turned off and on individually. 3DViewer will perhaps provide the most interesting views, but is also the most complex component of MRD 162 to use.

The inversions are presented both as static slices from the WinDisp 3DViewer as bitmap (.bmp) images, and as binary (.bin) images, which can be viewed using 3DViewer (discussion below). These images contain surface, flat and/or amplitude-enhanced maps of the data as translations of coloured grids; and line topography, line geology and imaged geology. These are set on an image of a three-dimensional box seen as a wire frame that contains the 3D image inversion products. Within the boxes, there are series of coloured shells, or iso-surfaces, that represent the inversion product. The shells may be thought of as three-dimensional contours, much as two-dimensional (2D) contours describe amplitudes on flat maps of data. As with 2D flat-map contours, where a single contour interval may be seen to describe the outline of a source body (the 0 contour on first vertical derivative magnetic maps for example), the 3D shells may have one surface that most closely describes the surface of the source body. Identifying the surface requires more direct knowledge of subsurface geology than is available here. It is best to think of the surfaces as descriptors of shape, attitude, location and strength, without providing an exact source surface.

Also identified, in Appendix 3, are the shell or isosurface values of the 3D images with their assigned colours. It will be seen that there is some variation in the colour assignments from area to area, although the general format is fairly consistent. Complete consistency in colour assignments has not been developed, in part because value contrasts and range can be different from area to area. In some areas, the contrasts may be low.

Project Areas

KAMISKOTIA AREA (INCLUDING THE GENEX DEPOSIT AREA IN WESTERN GODFREY TOWNSHIP)

General

Three-dimensional (3D) inversions were carried out on airborne magnetic and ground gravity surveys in the Kamiskotia study area. The area extends from Robb, Jameson and part of Jessop townships, in the north, to parts of Carscallen, Bristol and Ogden townships, in the south. All of Turnbull, Godfrey and part of Mountjoy townships, in the centre, are covered (*see* Figure 1a; *see* Appendix 1 for a more detailed area description). Data for the inversions were derived from gridded airborne magnetic and ground gravity data. The large area necessitated selections of 250 metre cells for the overview of the area.

The Genex deposit area within the Kamiskotia study area covers much of Godfrey Township, with additions from Turnbull, Carscallen and Bristol townships. The smaller study area around the Genex deposit used 100 metre cells.

Data Sources

The airborne data used were a combination of 2 fairly high-definition fixed-wing MEGATEM II magnetic surveys collected with electromagnetic surveys (Explorer's Alliance, 2001, unpublished data [note, except for the components used here, these data are not presently in the public domain]); and the Kamiskotia area survey for the Discover Abitibi Initiative: OGS 2003c) merged within a broader fixed-wing magnetic survey of earlier vintage (1989 Timmins area GEOTEM survey, published as part of OGS 2003b). The Explorer's Alliance 2001 survey consisted of 2 surveys flown at right angles. These 2 surveys were merged before merging with the later Discover Abitibi Kamiskotia area survey (southern boundary is immediately north of the Genex deposit). These surveys were merged by this author without special micro-levelling. Few joins or edge effects have developed and no obvious breaks are observed. The gravity survey was taken from a nominal 1 km station interval survey collected in 2001 as part of the Timmins Collaborative Gravity Survey Project (Dome-OGS) (OGS 2001), along with a few readings from the National Gravity Database (NRCan, Geomatics Canada). The 100 and 250 m cell sampling used here for the inversion, moderately to significantly undersampled and degraded the magnetic data, whereas this sampling significantly oversampled the gravity data.

Commentary

The Kamiskotia study area, with the Genex deposit area, is intruded by numerous north-trending magnetic dikes (Figures 2 and 3), making the geological stratigraphy with east-west strikes difficult to see, but is locally evident. Unfortunately, an inversion artifact developed at depth under the dikes appears as narrow streaking or bars oriented both east-west and north-south. This seems to have arisen because of the close spacing between the dikes and is generally a rare artifact in the inversion of the magnetic data. Attempts to diminish or remove this artifact resulted in loss of definition of real source events.

The slice images may be directly helpful in suggesting dips and body extents into the third dimension: Figure 4 is provided as an example. More slice images are available on MRD 162, where it is possible to view how the bodies behave as the slices are extended across the images. For example, in the folder Kamiskotia\3Dmag\genex\bitmap\, the slice sequence looking north across the Genex area magnetic data is shown by a series of bitmap files genmag30lookn0,1,2,3,4,5,6 and 7. As the user's familiarity with WinDisp 3DViewer improves, the slice tool (see top tool bar, "Clip Planes", pull-down menu which gives various aspects of slicing the image) may be used to develop new views across the section. Note that in the bitmap slices, there are views from the south as well as from the west.

Also view the combined magnetic and gravity images. These can be used to interpret the relationships between magnetic susceptibility bodies and gravity (both high and low) density bodies. Note, also, there are different ways of showing the surfaces when using 3DViewer. In the combined geology on magnetic binary image for the Kamiskotia area (see MRD 162 file in folder Kamiskotia\combined\kamain\binary\km_geol_on_mag_amp.bin), the high density colour has been made semi-transparent to differentiate from the magnetic responses.

SHAW DOME AREA, WITH TWO DETAILED AREAS

General

The study area extends from the southern parts of Tisdale, Whitney and Cody townships, in the north, to Adams, Eldorado and Langmuir townships, in the south. This covers essentially all of the Shaw Dome structure (see Figure 1a; see Appendix 1 for a more detailed area description). The Porcupine-Destor fault cuts across the northwesterly side of the area and closes the Shaw Dome to the northwest. The data grid was set at 250 m intervals for the inversion. This degraded the magnetic data somewhat, whereas the gravity data were unaffected.

Two smaller areas within this study area were selected for detailed study (see Appendix 1 for a more detailed area descriptions) and, although not changing the overall 3D images, these provide a focused set of images.

Data Sources

The magnetic data for the area derive from the Abitibi Supergrid (the Timmins GEOTEM I survey component of OGS 2003b) with an overlay of data from a helicopter-borne magnetic survey provided to Discover Abitibi Initiative by Outokumpu (OGS 2004a). This survey was flown in several blocks along the outer margin of the Shaw Dome. The gravity data were from the recent Timmins Collaborative Gravity Survey Project (Dome-OGS) (OGS 2001), with the addition of the National Gravity Database (NRCan, Geomatics Canada). The gravity data interval is nominally 1 km, but shorter interval road traverses on the Dome-OGS survey (OGS 2001) increased the resolution in this area.

For the main Shaw Dome study area, on MRD 162 (see Shaw Dome\sdmainmag\inversource), the inversion file for the magnetic data contains 2 versions: A and B. The A version was used to make the bitmap image file shown in Figure 5 and has a somewhat wider perspective looking east to west. Version B presents a slightly different image, extending more northerly. No binary files are presented for the B version, but users of the full WinDisp or UBC-GIF MeshTools3D will be able to access this inversion.

Commentary

The slice images (e.g., *see* Figure 5) may be directly helpful in suggesting dips and body extents into the third dimension. The combined magnetic and gravity inversions indicate relationships between magnetic susceptibility bodies and gravity (both high and low) density bodies. Note, also, there are different ways of showing the surfaces using 3DViewer, for example, in the combined image for the Shaw Dome detailed study area 2, the high density colour has been made gold to differentiate from the magnetic yellow.

The magnetic data are complex in this area (Figure 6), but careful isolation of components of the 3D image (especially using 3DViewer) shows features such as the contact around the Shaw granite (the circular magnetic low in the south central part of the area, i.e., no response) to have south-dipping contacts. The contacts are described by surrounding magnetic material. Toward the southeast corner, the magnetic body there dips northwest, indicating some crossing structure. It is interesting to note that this northwesterly dip does not match the expected south plunge off the south end of the Shaw Dome.

TISDALE TOWNSHIP-HOYLE POND-DOME MINE AREA

General

Two areas were selected for detailed study to complement the gold subproject in the Timmins area. These are over and around the gold deposits at the Dome and Hoyle Pond mines. One area covers the Dome Mine area (Tisdale Township), whereas 2 overlapping areas cover the Hoyle Pond area: Hoyle 1 and Hoyle 2 (*see* Figure 1a; *see* Appendix 1 for a more detailed area descriptions).

Data Sources

The magnetic data came from 2 sources. Data from a helicopter-borne magnetic survey by Placer Dome (Porcupine Joint Venture (PJV)) were provided to the author for this study. The PJV data are not in the public domain. This survey, flown with a sensor at 30 m and a line spacing of 100 m, represents a high resolution definition of the magnetic field. Two of the study blocks (Dome and Hoyle 1) extend into "gaps" (i.e., town areas not overflowed previously) and edges of this survey. The gaps were filled by magnetic data from the older Timmins GEOTEM I survey (Abitibi Supergrid portion of OGS 2003b). The magnetic sensor, set on a stringer on the aircraft at 120 m, with lines flown at 200 m, meant that the fill-in areas have lower resolution. The gaps filled do not represent significant areas within the study blocks. The merged data, when processed to 3D inversions, show little negative impact from the areas of fill-in. Some of the gaps were later replaced by later PJV high-resolution airborne magnetic data, but this was only a partial data replacement, as earlier inversions were not replaced.

The gravity data are all in public domain, being the combination of the National Gravity Database (generally a few widely spaced data points, with some road traverses) and the recent Timmins Collaborative Gravity Survey Project (Dome-OGS) (OGS 2001) 1 km spaced database. The gravity has a very much lower resolution than the magnetic data, because of the much larger data point intervals.

The topographic and geologic data represented as line outlines were provided by J.A. Ayer (Ontario Geological Survey) as ESRI® ArcGIS files (in NAD83), which were converted by the author to shape (.shp) files for further conversion into OASIS montaj™.

Tisdale-Deloro Townships Area

GENERAL

The Tisdale and Deloro townships study area extends from South Porcupine in the east to Timmins in the west, and includes the Dome Mine in the southeast corner and the Hollinger and McIntyre mines toward the northwest (*see* Appendix 1 for a more detailed area description). Structures and lithologies related to these mines and their surroundings can be viewed on the bitmap (.bmp) images, examples of which are Figure 7, which shows the geology draped on the amplitude-enhanced magnetic data and Figure 8, which shows the 10 km bandpass filter gravity draped on the amplitude-enhanced magnetic data. The study area is 10 km by 10 km making a convenient inversion file with cells of 100m x 100m. The depth of this inversion block is 2 km, with cells 50 m thick. This makes a large, but manageable, file for inversion. The gravity data were sampled at the same 100m x 100m x 50m interval for inversion, although it is recognized that the primary data do not permit resolution of source bodies at this scale.

COMMENTARY

Figure 9 shows a slice through a combined image of the 3D magnetic and gravity data with a geology map on the surface for reference. Mafic flows correlate with a gravity high, while the northern ultramafic flows are magnetic and show distinctive southerly dips, apparently crosscutting the larger, less sharply defined gravity event. The 3D gravity to the south suggests a north dip toward the Porcupine-Destor fault dips steeply to the north.

There are 2 versions of the 3D images for the Tisdale-Deloro study area on MRD 162. One version with "tismag" in the file name is larger, and was designed to extend west across north-trending Matachewan diabase (magnetic) dikes. Unfortunately, lattice artifacts developed in these images at the low contrast shells. The smaller version with "83" in the file names provides a more satisfactory image of the magnetic events. Both versions are presented to demonstrate limitations in the 3D method. Note, the various bitmap images that show distinctive dips on the several magnetic formations in the area.

HOYLE-WHITNEY TOWNSHIPS AREA

General

The Hoyle-Whitney townships study area is presented in 2 overlapping smaller areas (*see* Figure 1a; *see* Appendix 1 for a more detailed area descriptions). The Hoyle 1 area was too large to process conveniently with 100 m cells, so the processing went ahead with 200m x 200m x 100m cells. The somewhat smaller Hoyle 2 area was processed with 100m x 100m x 50m cells.

HOYLE 1 AREA

The Hoyle 1 study area extends from South Porcupine in the southwest corner to past the Kidd Creek metallurgical site in the northeast. The Hoyle 1 area overlaps the Hoyle 2 area. The various gold deposits, including Hoyle Pond and Pamour Mine, are central to this block. The Porcupine-Destor fault extends diagonally from east-central to the southwest corner of the map, largely identified along magnetic

features. In MRD 162, files for the Hoyle 1 area may be identified as "Hoyle" on some file names. Using the larger cells vertically, produced inversions to 4 km depth.

HOYLE 2 AREA

The Hoyle 2 study area extends 10 km west and 10 km north from the Pamour Mine and the Kidd Creek metallurgical site in the southeast corner. The Hoyle 1 area extends from the south 5 km into the Hoyle 2 area. Inversions for the Hoyle 2 area were extended to 2.5 km depth. The use of 100m x 100m x 50m cells permitted the development of higher resolution of the detail available in the magnetic data. In MRD 162, files for the Hoyle 2 area are identified with "h2" in the file names.

Commentary

The inversion process is a filter-smoothing process, and the loss of fine detail seen in the magnetic image cannot be avoided. There is greater detail present in the helicopter-borne magnetometer survey that could be resolved if smaller imaging cells were used. These data would permit the use of 50 m or even 25 m cells. The area to be inverted would have to be correspondingly smaller and the depth of the inversion would be smaller as well. There is no additional detailed information in the gravity data that could benefit from using smaller cells.

It will be seen that much of the inverted magnetic data shows terminations at depths of 1 km or less (Figures 10 and 11). This is especially noted with narrow dikes. This shows a limitation in the inversion process and the magnetic field detection for narrow features. It is likely that the dikes continue to depth, but are not seen in the inversion, and there is likely little information in the primary magnetic field from the deeper extents of these dikes. Broader deeper extending magnetic bodies, however, do show their deeper extending components in the inversions. Gravity bodies seen in the inversions do extend to depth (see Figures 10, 11 and 12). This deeper imaging probably derives from the widely spaced primary data points seeing the deeper elements of the source density bodies. That these deeper extensions in the gravity inversions may, in places, be artifacts, cannot be discounted.

Some limited filtering of the magnetic data was done to provide a smoother database or longer wavelength database for inversion. Such inversion was carried out, but is not presented here as the results are tentative. There needs to be more filtering and inversions on the product done to establish confidence in the value of using a filtered product.

Some correlation between magnetic highs and gravity highs is apparent especially with the large gravity high to the west in the Hoyle 1 area. Closer inspection, however, shows the narrow magnetic feature to lie along a trough in the gravity high (see Figure 10). Note, in this image, the magnetic feature dips south, conforming to the dip of the north component of the gravity high. Contrary to this, the large gravity high just to the south, dips north. The next slice east (see Figure 11) shows changes, especially in the magnetic data, where 2 differently dipping events lie in the enclosing gravity high. A magnetic feature further south dips to the north. The many slice images through the Hoyle 1 and Hoyle 2 magnetic and gravity 3D images provide a sense of the coherent as well as the complex behaviour of the rocks in this area.

TULLY-PROSSER TOWNSHIPS AREA

General

The Tully-Prosser townships study area was originally selected as one of the areas for mapping as a base metals subproject within the Greenstone Architecture Project, however, because of time constraints, this area was not mapped. The 3D inversions presented here represent the only completed work. The area studied covers the east half of Prosser Township and the west half of Tully Township (*see* Figure 1a; *see* Appendix 1 for a more detailed area description). For the inversions, 200 m cells were selected from the surface data, with 100 m cells on the vertical extending to 4000 m. This is the one area where it has appeared preferable to use the 20 km bandpass on the gravity. For reasons that are uncertain, the 10 km bandpass produced an image that was broken up and the 3D result was less than satisfactory.

Data Sources

Most of the magnetic data were developed from the Timmins MEGATEM II survey (OGS 2003c) flown in 2002 as a precursor to the start of the Discover Abitibi Initiative. A strip approximately 1.6 km wide was added to the south edge of this survey from the Abitibi Supergrid (OGS 2003b) to fill out the southern edge of the magnetic survey data over the townships. The gravity data were from the Timmins Collaborative Gravity Survey Project (Dome-OGS) (OGS 2001), where data have an interval of approximately 1 km.

Commentary

Images of the geology are presented with the 3D magnetic and gravity images showing a mixed assemblage of sediments and mafic and ultramafic flows to the south, changing to mafic to intermediate to felsic volcanic flows with some sediments, in the central and north parts of the area (Figure 13). These rocks are variously described by their magnetic and gravity responses. Significantly, the broad area of ultramafic rocks to the south is magnetically high and gravity low. It would seem that these rocks are serpentinized to become magnetic with lower densities developed. The sediments flanking the south of these volcanic rocks are both magnetic and gravity lows. The mafic volcanic rocks just north of the ultramafic volcanic rocks have higher densities with more modest magnetic responses. These and other correlations may be viewed in the images, especially where the geology is draped on the amplitude-enhanced magnetic images (*see* Figure 13).

The slice images (e.g., Figure 14; *see* MRD 162, related files with "slice" in file name in folder Tully_Prosser\3Dmag\bitmap) show a significant range in the pattern of dips across the area. Figure 14 (slice 2) shows north dips on the south side developed in the ultramafic flows, and south dips in ultramafic and mafic flows, central to the area. North dips are evident in the mafic volcanic rocks to the east as seen in the gravity (Figure 15). As with other areas, there is significant complexity evident that would require closer study than is possible here to fully resolve.

CURRIE TOWNSHIP AREA

General

The Currie Township study area extends 1.5 km into the surrounding townships (*see* Figure 1a; *see* Appendix 1 for a more detailed area description). It just falls short of crossing the Porcupine–Destor fault to the north (*see* Figure 1b). Two mafic volcanic units divided by a felsic band dominate the area. The inversions used 200 m X and Y data cells with 125 m Z data cells. The magnetic data inversions were carried to 3.75 km depth, whereas the gravity inversions extend to 5 km.

Data Sources

The magnetic data used for the inversion were from the Discover Abitibi, Porcupine–Destor–Pipestone high-resolution survey (OGS 2004b). A small portion of magnetic data from the Abitibi Supergrid (OGS 2003b) were added to the southeast corner of the area. The gravity data employed were a merging of the Discover Abitibi airborne survey data (OGS 2004c) and earlier ground-based data (OGS 2003a).

Commentary

The southern mafic volcanic rocks (currently assigned to the Lower Blake River assemblage; Ayer et al. 2005) are both magnetically active and high, and have a higher density expressed by a higher residual gravity response. The combined inversion image (Figure 16) describes a synclinal feature in the magnetic data within the southerly volcanic rocks. The gravity within this area consistently shows southerly dips, conforming to the north contact, but offering a contrasting dip to the magnetic data on the south contact. The reasons for this are uncertain. The mafic volcanic rocks to the north (Tisdale assemblage) are bimodal gravity response suggesting low densities to the south and higher densities to the north. These dip north (as well as vertical, depending on the on-strike location), apparently in conforming with the Porcupine–Destor fault lying just to the north.

While not a designated part of the 3D inversion process, the images with the geology draped on the amplitude-enhanced magnetic images show significant features. The geological description of the northeasterly striking Abitibi diabase dikes (e.g., Figure 17) needs adjustment on both the north and south dikes where the magnetic high response identifying the dikes departs from the geological map. A similar adjustment of the felsic volcanic unit (Upper Tisdale assemblage) contact is needed where the magnetic data show the geology departing from the magnetic data (should be low). Note, there are subtle details within the magnetic low volcanic rocks (Tisdale assemblage) to the northeast, which represent slightly magnetic horizons within the unit, possibly describing folds.

Note that the northern Abitibi diabase dike dips steeply south on the section view as seen in Figure 18. Similar dips may be observed using the combined binary files (e.g., *see* MRD 162: Currie\combined\binary\curmag_magamp_geo_10000.bin, and Currie\3Dmag\binary\curmag_all.bin). In these images, the Matachewan diabase dikes (trending north-south) are vertical, but show limited depth extent. The depth limitation on the inversion develops on narrow features, and is thought to be an artifact of the inversion that does not permit deep viewing of thin, long, linear features.

MUNRO TOWNSHIP AREA

General

The study area covers Munro Township, extending short distances into Beatty and McCool townships, to the west and east, respectively, but further into Warden and Guibord townships to the north and south, respectively (*see* Figure 1a; *see* Appendix 1 for a more detailed area description). The area covers principally, mafic and ultramafic volcanic rocks of the Kidd–Munro assemblage, with Porcupine assemblage sediments to the north and south (*see* Figure 1b). The area extends across the Pipestone fault, but stops north of the Porcupine–Destor fault to the south. The inversions used 200 m cells for the surface data and developed the third dimension with 125 m cells. The magnetic inversions extend 3.75 km in depth, whereas the gravity inversions extend to 5.0 km in depth.

Data Sources

The magnetic data are from the Discover Abitibi MEGATEM II survey of the Kidd–Munro, Blake River area (OGS 2003d). The gravity data are from the previously existing ground-based survey (OGS 2003a) with the Discover Abitibi airborne gravity survey (OGS 2004c) added to the southern part of the area.

Commentary

Magnetic responses are strongest on ultramafic intrusive rocks, and more moderate on ultramafic volcanic rocks. Some response is present in the mafic volcanic rocks (Figure 19). The 3D magnetic image (Figure 20) indicates a tight syncline on the northerly magnetic data (steep north dip on the south unit of the north feature, steep south dips on the 2 north units). This is supported by the regional geology map.

The 3D positive gravity develops a contrary view, suggesting a north dip within the north magnetic feature (Figure 21). It is not clear (as in Currie Township) why these differences occur. The gravity and magnetic data are mixed in their correlations, as can be seen on the combination of the magnetic and the negative component of the gravity (Figure 22).

CLIFFORD–BEN NEVIS–ARNOLD–KATRINE TOWNSHIPS AREA

General

This study area is contained to the boundaries of these 4 townships (*see* Figure 1a; *see* Appendix 1 for a more detailed area description). The geology shows dominantly intermediate volcanic rocks (Blake River assemblage) with felsic volcanic rocks surrounding the core Clifford stock (granodiorite) and mafic volcanic rocks to the south (*see* Figure 1b). The inversions used 200 m cells for the surface data and developed the third dimension with 125 m cells. The magnetic inversions extend to depths of 3.75 km, whereas the gravity inversions extend 5.0 km.

Data Sources

The magnetic data were developed from the Discover Abitibi MEGATEM II survey of the Kidd–Munro, Blake River area (OGS 2003d). An additional 3 km of data were added to the magnetic data from the Abitibi Supergrid (OGS 2003b). The splice line between these 2 surveys does not affect the inversion. The gravity data are from the regional ground-based gravity survey (OGS 2003a).

Commentary

Generally, the responses in the magnetic and gravity data are subdued in amplitude across the area. Both magnetic and gravity data, however, find a focus in the responses over and around the Clifford stock (Figure 23). There is a large doughnut-shaped gravity high surrounding the intrusion and its associated felsic volcanic rocks. The circular gravity low, the felsic volcanic rocks, contains a doughnut-shaped magnetic high (*see* Figure 23) showing the intrusion to have a magnetic rim. The slice combination image through the models (Figure 24) shows that a gravity low surrounds the south-dipping magnetic model. The 3D gravity low suggests a bowl shape as it narrows to depth. These features are best seen on the 2D image (*see* MRD 162: Clifford_Ben Nevis_Arnold_Katrine\combined\binary\bnk_geol_flat.bin), where magnetic and gravity (negative and positive) data and geology are brought together; this image shows the magnetic component of the Clifford stock plunges southeast, somewhat across the gravity low.

The mafic volcanic rocks (gravity high and complex magnetic) to the south in Arnold Township appear to dip steeply north in the 3D gravity images. The magnetic data are insufficiently resolved to support this. Both magnetic and gravity data suggest revisions of the contact to further south of where it is drawn on the regional map.

TECK TOWNSHIP AREA

General

The study area extends 1 to 2 km into the adjacent townships surrounding Teck Township (*see* Figure 1a; *see* Appendix 1 for a more detailed area description). The Larder Lake–Cadillac deformation zone extends northeasterly across the southern third of the area, through and along the south edge of sediments, intrusive rocks and volcanic rocks of the Timiskaming assemblage (*see* Figure 1b). The inversions used 200 m cells for the surface data and developed the third dimension with 125 m cells. Both the magnetic and gravity inversions extend to 5.0 km.

Data Sources

The magnetic data are primarily from the Discover Abitibi high-resolution survey of the Kirkland Lake–Larder Lake area (OGS 2004d). Fill-ins from the Abitibi Supergrid (OGS 2003b) were made to the northwest and southeast corners, which were not covered by the Kirkland Lake–Larder Lake survey. The gravity data are from the regional ground-based gravity survey (OGS 2003a).

Commentary

Gravity is low within the Timiskaming assemblage sediments, volcanic rocks and intrusive rocks north of the Larder Lake–Cadillac deformation zone (Figure 25). The 3D gravity data suggest steeply dipping bodies on both the high and low density inversions (*see* Figure 25). In Figure 26, magnetic data form a series of steeply dipping bands that show elements of both southeast and northwest dips. The magnetic data suggest that the Larder Lake–Cadillac deformation zone dips north (Figure 27), assuming that the magnetic data conform to the structure, and the structure lies along the south edge of the central magnetic data in the image.

Parts (but not all) of the mafic volcanic rocks to the south and the margin of the Otto stock are magnetic (Figure 28). The dip on this magnetic anomaly looks steep with elements to the south. The 3D gravity appears to dip to the south along this contact.

GAUTHIER TOWNSHIP AREA

General

The study area is almost entirely contained within Gauthier Township (*see* Figure 1a; *see* Appendix 1 for a more detailed area description). The Larder Lake–Cadillac deformation zone lies diagonally across the south to southeast part of the area (Figure 29; *see* Figure 1b). This image includes the geology (Ayer and Trowell 2000) draped on amplitude-enhanced magnetic data as seen from overhead. The inversions used 200 m cells for the surface data and developed the third dimension with 125 m cells. The magnetic inversions extend 3.75 km, whereas the gravity inversions extend 5.0 km.

Data Sources

The magnetic data are from the Discover Abitibi, high-resolution survey of the Kirkland Lake–Larder Lake area (OGS 2004d). The gravity data are from the regional ground-based gravity survey (OGS 2003a).

Commentary

Mafic volcanic rocks, south and north of the sediments, volcanic rocks and porphyries of the Timiskaming assemblage, show magnetic response (Figure 30). Intermediate volcanic rocks of the Tisdale assemblage across the north are magnetically low. Gravity highs track mafic volcanic rocks, but, in addition, suggest other high density events not apparent on the geology map. The gravity high central to the area lies at the sediments–felsic volcanic rock contact, suggesting possible mafic volcanic rocks at this location. The magnetic high at this location supports this interpretation. There is a magnetic low south of this high, which contains, in part, a porphyry body. The porphyry is not fully the source of the magnetic low. (The 3D combined magnetic and gravity image on MRD 162, Gauthier\combined\binary\gau_mag_all_grv_all.bin, shows these features). The south contact of the mafic volcanic rocks to the north shows a south dip on the 3D inversions.

Conclusions

This report represents a fairly extensive and in-depth examination of Abitibi geology in three dimensions through the use of inversion processes that have only recently come into widespread use. Generally, 3D inversion has been applied to specific or contained magnetic and/or gravity responses (Li and Oldenberg, 1996, 1998a). These responses have been shown to be reasonably resolvable in their definition of contained three-dimensional bodies. The present study covers a range of lithologies with a range of magnetic and gravimetric responses that has extended the cases and possibly exposed limitations or challenges in the application of the 3D method (see various statements documenting conflicting results between magnetic and gravity data in this report, and the various depth limitations (magnetic) and extensions (gravity) that may be questioned). Using uncontrolled inversions alone, the results have demonstrated that inversions can be developed over large areas with reasonably believable results. Extrapolations from surface geology into the third dimension with the inversions have direct implications on the dip, shape and structure of the lithologies below the surface.

The products of this report have integrated surface geology and magnetic and gravity data through the use of the WinDisp software that has provided images that contain much more than can be achieved from simple overlays (3D volumes with gravity and magnetic inversions along with enhanced amplitude maps at the surface with mixed parameter products). This integration of products brings us closer to building positive synergies where correlations between geology and potential field geophysics can be developed.

Only a small part of the information has been developed to produce printed images for this report. There are many more images in the folders on MRD 162 and, by including WinDisp 3DViewer with those files, it is hoped that the user will realize there is much more available when that software is utilized for further analysis. Three-dimensional space cannot be fully appreciated if the space is not seen in at least a representation of three dimensions. Even the amplitude-enhanced images, while not truly 3D, draw out greater appreciation of the geology, magnetic and gravity data, when viewed with 3DViewer.

The inversion output files (.den and .sus, along with their associated .mesh files) are presented to provide the opportunity for the inversion products to be brought into other viewing systems (e.g., GoCAD or GeoExpress2000). Integration of these inversions with geology from another perspective might further develop the understanding of the 3D geology across the region. The opportunity also remains to investigate controlled 3D inversions. This has not been carried out in this subproject, and remains a challenge to be tested.

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Appendix 1

Study Area Definitions

All Universal Transverse Mercator (UTM) co-ordinates are in Zone 17 using North American Datum 1983 (NAD83). All locations are shown on Figure 1a.

Kamiskotia Area

The overall Kamiskotia study area is large, and extends in the north from the eastern side of Côté Township through Robb and Jameson townships, through the western half of Jessop Township; across Massey, Turnbull, Godfrey and Mountjoy townships in the centre; and, in the south, extends from the northeastern portion of Whitesides, through Carscallen and Bristol townships, into the western half of Ogden Township. The area is defined by UTM co-ordinates:

EAST: 445000 470000 NORTH: 5360250 5385000

GENEX DEPOSIT AREA

The Genex deposit area covers much of Godfrey Township (where the deposit lies), and parts of Turnbull, Carscallen and Bristol townships. The area is defined by UTM co-ordinates:

EAST: 453000 463000 NORTH: 5364000 5374000

Shaw Dome Area, with Two Detailed Areas

The overall Shaw Dome study area covers Shaw and Eldorado townships and encompasses most of Deloro and Adams townships, to the west, and Carman and Langmuir townships, to the east. The area extends slightly to the north into Tisdale, Whitney and Cody townships. The general study area is defined by UTM co-ordinates:

EAST: 478000 502250 NORTH: 5347600 5368600

SHAW DOME DETAIL AREA 1

Detailed study area 1 is defined by UTM co-ordinates:

EAST: 484500 501900 NORTH: 5349000 5360000

SHAW DOME DETAIL AREA 2

Detailed study area 2 is defined by UTM co-ordinates:

EAST: 477000 484000 NORTH: 5357000 5363900

Tisdale-Deloro Townships Area

The Tisdale-Deloro study area extends from South Porcupine in the east to Timmins in the west, including the Dome Mine in the southeast corner and Hollinger and McIntyre mines toward the northwest. All of Tisdale, much of Deloro and parts of Mountjoy and Ogden townships are covered by this study area. The area is defined by UTM co-ordinates:

EAST: 471000 485000 NORTH: 5363200 5376000

Hoyle-Whitney Townships Area

The Hoyle-Whitney study area is presented in 2 overlapping areas, identified as Hoyle 1 (or just Hoyle on some file names on MRD 162), and Hoyle 2 (file names with h2 on MRD 162).

HOYLE 1 AREA

The Hoyle 1 study area extends from South Porcupine in the southwest corner to past the Kidd Creek metallurgical site in the northeast. The area lies in the south half of Hoyle Township and the northern portion of Whitney Township. It extends into Matheson and Cody townships to the east and just enters Murphy and Tisdale townships to the west. The Hoyle 1 area is defined by UTM co-ordinates:

EAST: 484000 497000 NORTH: 5370000 5380000

HOYLE 2 AREA

The Hoyle 2 study area extends from the Pamour Mine and the Kidd Creek metallurgical site in the southeast corner 10 km west and 10 km north. Hoyle 1 extends from the south 5 km into Hoyle 2. Hoyle 2 covers Hoyle Township with little extension into the surrounding townships. The Hoyle 2 area is defined by UTM co-ordinates:

EAST: 485000 495000 NORTH: 5375000 5385000

Tully-Prosser Townships Area

The Tully-Prosser study area covers the eastern portion of Prosser Township, the western portion of Tully Township and extends into Lucas and Duff townships, to the north, and Wark and Gowan townships to the south. The area is defined by UTM co-ordinates:

EAST: 481000 490000
NORTH: 5393000 – gravity (5394600 – magnetic) 5407000

Currie Township Area

The overall Currie study area encompasses Currie Township, and extends slightly into the surrounding townships of Bond, Stock, Taylor, Carr, McCann, Bowman, Egan and Sheraton. The area is defined by UTM co-ordinates:

EAST: 523000 534000 NORTH: 5366000 5377000

Munro Township Area

The overall Munro study area encompasses Munro Township, and extends a short distance into the surrounding townships of Beatty, Coulson, Warden, Milligan, Michaud, Guibord and Hislop. The area is defined by UTM co-ordinates:

EAST: 553000 565000 NORTH: 5373000 5388000

Clifford-Ben Nevis-Arnold-Katrine Townships Area

The overall Clifford-Ben Nevis-Arnold-Katrine study area contains almost exactly these townships, without extensions into the surrounding townships. The area is defined by UTM co-ordinates:

EAST: 582000 602000 NORTH: 5338000 5357600

Teck Township Area

The overall Teck study area encompasses Teck Township, and extends only slightly east into Lebel Township and south into Otto Township. The area is defined by UTM co-ordinates:

EAST: 562000 574000 NORTH: 5326000 5337800

Gauthier Township Area

The overall Gauthier study area encompasses Gauthier Township, and extends slightly west into Lebel Township. The area is defined by UTM co-ordinates:

EAST: 581600 592400 NORTH: 5328400 5338400

Appendix 2

References to Image Files on MRD 162 for Figures 2 to 30

INTRODUCTION

Figures 2 to 30 (Charts A to D, back pocket) are derived from bitmap files found on Miscellaneous Release—Data (MRD) 162. The following lists the files by path (folder names separated with “\”) and file name so the original file images and additional, associated images may be viewed.

Kamiskotia

Figure 2 Kamiskotia\3Dmag\kamain\bitmap\kam_mag_amp_look_N.bmp

Figure 3 Kamiskotia\combined\kamain\bitmap\kam_mag_3D_grv_3d_over.bmp

Figure 4 Kamiskotia\3Dmag\kamain\bitmap\kam_mag_30_deg_slice_5.bmp

Shaw Dome

Figure 5 Shaw Dome\3Dmag\sdmainmag\bitmap\sd_mag_30s_45_slice_4.bmp

Figure 6 Shaw Dome\3Dmag\sdmainmag\bitmap\sd_mag_30_vert.bmp

Tisdale-Deloro

Figure 7 Tisdale_Deloro\combined\bitmap\tis_geol_on_mag_amp_look_NE.bmp

Figure 8 Tisdale_Deloro\combined\bitmap\tis_grav_on_mag_amp_look_NE_over.bmp

Figure 9 Tisdale_Deloro\combined\bitmap\tis_grav_mag_3D_geol_slice_look_W.bmp

Hoyle-Whitney

Figure 10 Hoyle_Whitney\combined\bitmap\hoyle1\h1_mag_3D_grv_3D_look_E.bmp

Figure 11 Hoyle_Whitney\combined\bitmap\hoyle1\h1_mag_3D_grv_3D_look_E_slice1.bmp

Figure 12 Hoyle_Whitney\3Dgrav\hoyle2\bitmap2\h2_grv_45_look_N_grav.bmp

Tully-Prosser

Figure 13 Tully_Prosser\3Dmag\bitmap\tpmag_amp_geo_drape_1_look_E.bmp

Figure 14 Tully_Prosser\3Dmag\bitmap\mag_3D_geol_mag_amp_look_E_slice_2.bmp

Figure 15 Tully_Prosser\3Dgrav\bitmap\tp_grav_3D_geo_look_W_over.bmp

Currie

Figure 16 Currie\combined\bitmap\cmag_grv_amp_look_west.bmp

Figure 17 Currie\combined\bitmap\curmag_geo_draped_on_mag12.bmp

Figure 18 Currie\combined\bitmap\curmag_geo_amp_mag_3D_look_NE.bmp

Munro

Figure 19 Munro\3Dmag\bitmap\munro_mag_geol_on_3D_look_E_over.bmp

Figure 20 Munro\3Dmag\bitmap\munro_mag_look_W.bmp

Figure 21 Munro\combined\bitmap\grv_mag_all_look_w_3.bmp

Figure 22 Munro\combined\bitmap\mun_neg_grv_mag_all_look_w.bmp

Clifford–Ben Nevis–Arnold–Katrine

Figure 23 Clifford_Ben Nevis_Arnold_Katrine\combined\bitmap\
cbnk_mag_grav_pos_neg_over_geo.bmp

Figure 24 Clifford_Ben Nevis_Arnold_Katrine\combined\bitmap\
cbnk_mag_grav_pos_neg_slice2_look_E_geo.bmp

Teck

Figure 25 Teck\combined\bitmap\teck_mag3D_grav3D_look_NE_grav_amp.bmp

Figure 26 Teck\combined\bitmap\teck_mag3D_grav3D_look_NE_mag_amp_slice3.bmp

Figure 27 Teck\combined\bitmap\tkmag3D_grav_3Dneg_look_SW_slice.bmp

Figure 28 Teck\3Dmag\bitmap\teck_geol_on_mag_3D_transp_over.bmp

Gauthier

Figure 29 Gauthier\3Dmag\bitmap\gau_geol_on_mag_amp.bmp

Figure 30 Gauthier\combined\gau_mag3D_grv3D_mag_amp_look_W_slice_1.bmp

Appendix 3

Three-Dimensional Isosurface Descriptions

INTRODUCTION

Listed here are the shell or isosurface values of the 3D images with their assigned colours. It will be seen that there is some variation in the colour assignments from area to area, although the general format is fairly consistent. Complete consistency in colour assignments has not been developed, in part because value contrasts and range can be different from area to area. In some areas, the contrasts may be low.

Kamiskotia Study Area

INVERSION PRODUCTS

The magnetic shells are coloured as

1000	white
2500	grey
5000	aquamarine
7500	light green
10000	light yellow
20000	orange
30000	pink

The positive gravity data are coloured as

.001	light grey
.005	grey
.01	aquamarine
.02	light green
.03	light yellow
.04	pink
.05	orange
.075	red

The negative gravity shells are coloured as:

.002	grey
.005	blue-grey
.01	dark blue
.02	dark green
.03	yellow – grey (khaki)
.04	dark orange
.05	dark red
.075	dark brown

GENEX STUDY AREA

Inversion Products

The magnetic shells are coloured as

1000	white
2500	grey
5000	aquamarine
7500	light green
10000	light yellow
20000	orange
30000	pink

The positive gravity data are coloured as

.001	white
.0025	grey
.005	aquamarine
.0075	light green
.01	light yellow
.025	pink/gold
.05	orange
.075	red

The negative gravity shells are coloured as:

.001	dark orange
.01	purple-grey
.02	dark orange/brown
.03	yellow - grey (khaki)
.04	dark green
.05	dark blue
.07	dark grey

Shaw Dome

INVERSION PRODUCTS

The magnetic data are coloured as

5000	white
10000	grey
20000	aquamarine
30000	light green
40000	light yellow
50000	orange
60000	red

The gravity data are coloured as

.002	white
.005	grey
.01	aquamarine
.02	light green
.03	light yellow
.04	orange
.05	red
.06	brown

The gravity shells are represented both as positive and negative density contrasts, so that the negative gravity data colours are

.005	blue-grey
.01	dark blue
.02	dark green
.03	yellow – grey (khaki)
.04	dark orange
.05	dark red
.06	dark brown

SHAW DOME DETAIL 1

Inversion Products

The magnetic data are coloured as

5000	grey
10000	aquamarine
20000	light green
30000	light yellow
40000	orange
50000	pink
70000	red

The gravity data are coloured as

.001	white
.0025	grey
.005	aquamarine
.0075	light green
.01	light yellow
.025	orange
.05	pink
.1	red

The gravity shells are represented both as positive and negative density contrasts, so that the negative gravity data colours are

.0025	light purple
.005	aqua/grey
.0075	grey/apple green
.025	grey/gold
.04	khaki/grey
.05	dark khaki

SHAW DOME DETAIL 2

Inversion Products

The magnetic data are coloured as

5000	white
10000	grey
20000	aquamarine
30000	light green
40000	light yellow
50000	orange
60000	red

The gravity data are coloured as

.001	white
.005	grey
.01	aquamarine
.02	light green
.03	light yellow
.04	orange
.05	red
.06	brown

The gravity shells are represented both as positive and negative density contrasts, so that the negative gravity data colours are

.005	blue-grey
.01	dark blue
.02	dark green
.03	yellow – grey (khaki)
.04	dark orange
.05	dark red
.06	dark brown

Tisdale-Deloro

Structures and lithologies related to the mines and their surroundings can be viewed on the bitmap images. The area is 10 km by 10 km making a convenient inversion file with cells of 100m x 100m. The depth of this inversion block is 2 km, with cells 50 m thick. This makes a large, but manageable, file for inversion. The gravity data were sampled at the same 100m x 100m x 50m interval for inversion, although it is recognized that the data do not permit resolution of source bodies to this scale.

Some variations at the extremities of this block may be found due to variances in the grid sampling process. A version of the magnetic block has been extended west to 469400E in an attempt to avoid edge effects from northerly trending dikes along the west side of the block. Magnetic images of both the smaller and larger areas are presented in the files.

INVERSION PRODUCTS

The magnetic shells are coloured as

5000	white
10000	grey
20000	aquamarine
30000	light green
40000	yellow
50000	orange
70000	pink
100000	dark red

The gravity shells are coloured as

Positive	.001	dark grey
	.005	aquamarine
	.01	light green
	.05	light yellow
	.1	orange

Negative (done on a smaller area)

.002	light grey
.005	dark purple/blue
.01	dark green/grey
.02	green/grey
.03	khaki
.04	grey/orange
.05	dark pink

Hoyle-Whitney

GENERAL

Hoyle is presented in 2 overlapping areas, identified as Hoyle 1 (or just Hoyle on some file names), and Hoyle 2 (file names with h2). Hoyle 1 was too large to process conveniently with 100 m cells, so the processing went ahead with 200m x 200m x 100m cells. The somewhat smaller area Hoyle 2 was processed with 100m x 100m x 50m cells.

HOYLE 1

Use of vertically larger cells for the Hoyle 1 area produced inversions to 4 km depth.

Inversion Products

The shells have been coloured according to physical property contrast amplitudes as derived from the modelling. The magnetic data are in SI units of 10^6 . The highest value contrast surfaces developed here

are 60000; the lowest 5000. The gravity data read in gm/cc. The highest values developed in the model generally are .06, the lowest is .002. Some presentations have expanded on this

The magnetic data are generally coloured as

5000	white
10000	grey
20000	aquamarine
30000	light green
40000	light yellow
50000	orange
60000	red

The magnetic data are represented as positive susceptibility contrasts only. File names on the binaries identify these numbers generally as thousands in the name. For example, the magnetic shell for 20,000 in Hoyle 1 is hoym83a20.bin (colour aquamarine).

The gravity data are generally coloured as

.002	white or light grey
.005	grey
.01	aquamarine
.02	light green
.03	light yellow
.04	orange
.05	red
.06	brown

The gravity shells are represented both as positive and negative density contrasts. The negative gravity data colours generally are

.005	blue-grey
.01	dark blue
.02	dark green
.03	yellow – grey (khaki)
.04	dark orange
.05	dark red
.06	dark brown

The density lends itself to viewing a negative contrast from some median level, where there as many values below a background as above. The background level for the magnetic data is at a base where most of the values lies above. There are essentially no negative values in the magnetic data (and no inversions done).

Colours assigned can vary, especially where magnetic data and gravity images have been combined. This variance in colour has been done in places for emphasis and contrast.

HOYLE 2

Inversions for the h2 block were extended to 2.5 km depth. The use of 100m x 100m x 50m cells has permitted the development of higher resolution of the detail available in the magnetic data.

Inversion Products

The shells have been coloured according to physical property contrast amplitudes as derived from the modelling. The magnetic data are in SI units of 10^6 . The highest value contrast surfaces developed here are 60000. The lowest 5000. The gravity data read in gm/cc. The highest values developed in the model generally are .06, the lowest is .002. Some presentations have expanded on this

The magnetic data are generally coloured as

1000	white
2000	light grey
3000	dark grey
4000	aquamarine
5000	light green
7500	light yellow
10000	orange
25000	red

The magnetic data are represented as positive susceptibility contrasts only. File names on the binary files identify these numbers generally as thousands in the name. For example, the magnetic shell for 20,000 in Hoyle 1 is hoym83a20.bin (colour aquamarine).

The gravity data are generally coloured as

.001	white
.002	light grey
.005	grey
.01	aquamarine
.02	light green
.03	light yellow
.04	orange
.05	pink

The gravity shells are represented both as positive and negative density contrasts. The negative gravity data colours generally are

.001	blue-grey
.002	dark blue
.005	dark green
.01	yellow - grey (khaki)
.02	dark orange
.03	grey-pink
.06	dark pink

The density lends itself to viewing a negative contrast from some median level, where there as many values below a background as above. The background level for the magnetic data is at a base where most of the values lies above. There are essentially no negative values in the magnetic data (and no inversions done).

Colours assigned can vary, especially where magnetic and gravity images have been combined. This variance in colour has been done in places for emphasis and contrast.

Tully-Prosser

The magnetic and gravity data have been selected with a 200 m cell.

INVERSION PRODUCTS

The magnetic data are generally coloured as

2500	white
5000	grey
10000	aquamarine
15000	light green
20000	orange
25000	pink
30000	red

The gravity data are generally coloured as

.001	white or light grey
.005	grey
.01	aquamarine
.02	light green
.03	light yellow
.05	pink
.07	red
.1	brown

Currie

INVERSION PRODUCTS

The magnetic shells are coloured as

5000	white
10000	grey
20000	aquamarine
30000	light green
40000	yellow
50000	orange
70000	pink
100000	dark red

The gravity shells are coloured as

Positive	.001	dark grey
	.005	aquamarine
	.01	light green
	.025	light yellow
Negative	.001	light purple
	.005	dark aquamarine
	.01	dark green
	.05	dark khaki

Munro

INVERSION PRODUCTS

The magnetic shells are coloured as

1000	white
5000	grey
10000	aquamarine
20000	light green
30000	yellow
40000	orange
50000	pink
70000	dark red
100000	dark brown

The gravity shells are coloured as

Positive	.001	dark grey
	.005	aquamarine
	.01	light green
	.05	light yellow
	.1	orange
Negative	.001	light purple
	.005	dark aquamarine
	.01	dark green
	.05	dark orange/brown
	.1	dark brown

Clifford-Ben Nevis-Arnold-Katrine

INVERSION PRODUCTS

The magnetic shells are coloured as

500	grey
1000	aquamarine
2500	light green
5000	yellow

The gravity shells are coloured as

Positive	.001	dark grey
	.005	aquamarine
	.01	light green
	.025	gold
	.05	light yellow
Negative	.001	light purple
	.005	dark aquamarine
	.01	pale green/yellow
	.02	bright green
	.025	green/gold
	.03	dark khaki
	.04	dark orange
	.05	pale pink/brown

Teck

INVERSION PRODUCTS

The magnetic shells are coloured as

5000	white
10000	grey
20000	aquamarine
30000	light green
40000	yellow
50000	orange
70000	pink
100000	dark red

The gravity shells are coloured as

Positive	.001	dark grey
	.005	aquamarine
	.01	light green
	.05	light yellow
	.1	orange
Negative	.005	dark aquamarine
	.01	dark green
	.05	dark khaki
	.1	dark pink

Gauthier

INVERSION PRODUCTS

The magnetic shells are coloured as

5000	grey
10000	aquamarine
20000	light green
30000	yellow
40000	orange
50000	pink
70000	red
100000	dark red

The gravity shells are coloured as

Positive	.005	aquamarine
	.01	light green
	.02	light yellow
	.03	orange
	.05	pink
Negative	.001	light purple
	.005	blue
	.01	dark aquamarine
	.05	dark khaki/green
	.1	dark pink

Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	Multiplied by	Gives	Imperial Unit	Multiplied by	Gives
LENGTH					
1 mm	0.039 37	inches	1 inch	25.4	mm
1 cm	0.393 70	inches	1 inch	2.54	cm
1 m	3.280 84	feet	1 foot	0.304 8	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	1.609 344	km
AREA					
1 cm ²	0.155 0	square inches	1 square inch	6.451 6	cm ²
1 m ²	10.763 9	square feet	1 square foot	0.092 903 04	m ²
1 km ²	0.386 10	square miles	1 square mile	2.589 988	km ²
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
VOLUME					
1 cm ³	0.061 023	cubic inches	1 cubic inch	16.387 064	cm ³
1 m ³	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m ³
1 m ³	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m ³
CAPACITY					
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	4.546 090	L
MASS					
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	31.103 476 8	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	0.453 592 37	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	907.184 74	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	0.907 184 74	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	1016.046 908 8	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	1.016 046 90	t
CONCENTRATION					
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

**OVERSIZE MAPS
NOT FILMED**

**CARTES
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